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Narrow bandwidth tunable optical filter using apodized sampled gratings in InP-based generic integration platform

(Student paper)

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We demonstrate a narrow bandwidth tunable optical filter based on cascaded multi-mode interference (MMI) and apodized sampled grating (ASG) on generic InP integration platform. The transmission mode bandpass filter on an active-plus-passive platform can achieve narrow 3 dB bandwidth (BW <0.3 nm) with low non-adjacent/adjacent channel crosstalk (ER > 45.8, SER > 80 dB), low insertion loss (IL < 5 dB), and wide tuning range (FSR = ~20 nm), making it potentially be applied to future densely integrated optical THz heterodyne system.

Keywords: *InP, Foundry, 3-dB Bandwidth, Filter, Apodized Sampled Grating*

INTRODUCTION

Integrated tunable filter is a very important building block for optical data communications and signal processing applications, such as wavelength division multiplexing (WDM), THz heterodyne system, microwave signal generation system, etc. The filter is always required to have narrow bandwidth (BW < 0.5 nm) for THz heterodyne system to select single wavelength for optical injection locking. Many works have been done on the narrow BW filter in recent years, using different structures, like Bragg gratings (BGs), Mach–Zehnder interferometers (MZI), ring resonators, arrayed-waveguide grating (AWG), sampled grating (SG), etc. The reflection from BG needs external device like an optical circulator to extract the filtered light, and the tuning range is restricted by the limited effective index change[1]; the MZI-based filter needs several different elements to achieve narrow BW wavelength selection, which causes high optical loss, and the tuning mechanism can be complicated[2]; The ring resonator with low crosstalk and low insertion loss (IL) is always used in high-index contrast platform. It utilizes the vernier effect to enlarge the free spectral range (FSR)[3]; the AWG-based filter is combined with semiconductor optical amplifiers (SOAs). The circuit requires a large number of SOA gates to control the wavelength selection, bringing challenges in cost and flexibility[4]. In the meanwhile, The sampled gratings (SGs) with comb-like reflection spectrum, always be studied as wide FSR filter using vernier effect, and the BW can be largely reduced using low coupling coefficient of SGs[5,6], which is a promising device to achieve narrow BW tunable optical filter.

The InP-based Photonic Integrated platform is based on butt joint active-passive epitaxy, which provides more flexibility to achieve optical system on one chip[7]. So far narrow BW optical tunable filters are not available on this platform. However, the low-index contrast layer stack in this platform is suitable to achieve such device with SGs.

In this paper, we aim to achieve a narrow bandwidth optical wavelength-tuning filter with low adjacent/non-adjacent channel crosstalk (high extinction ratio/side-lobe extinction ratio, ER/SER), low insertion loss (IL), wide FSR on InP-based generic integration platform. The filter is composed of multiple cascaded multi-mode interferences (MMIs) and ASGs. The transfer matrix method has been used in this work, in order to simulate the reflection spectrum of the filter. The ASG using Gaussian type apodization to modulate the duty ratio of SG periodically can largely increase the SER of the reflection spectrum. Following are the detailed introduction and simulation results of our designed transmission mode bandpass filter.

RESULTS

The layers of the shallow-etched grating (on top of the substrate and below the top cladding) in InP-based generic integration platform is depicted in Fig. 1(a). The gratings are buried in the shallow etched waveguide layer, which have optical properties fixed by the platform, including the coupling coefficient κ as 50 cm^{-1} and effective index n_{eff} as 3.266. The grating layer thickness T and the n-InP layer thickness D in the waveguide core are both 30 nm, and the width of shallow waveguide w is 2 μm[7]. Λ denotes the period of the grating. When selecting the Bragg wavelength λ_{Bragg} as 1550 nm, the Λ can be calculated as 237.3 nm through the Bragg equation $\lambda_{Bragg} = 2n_{eff}\Lambda$. Meanwhile, the duty ratio of grating dr_{BG} = a/ Λ is set to 0.5 for low IL and symmetrical reflection spectrum output.

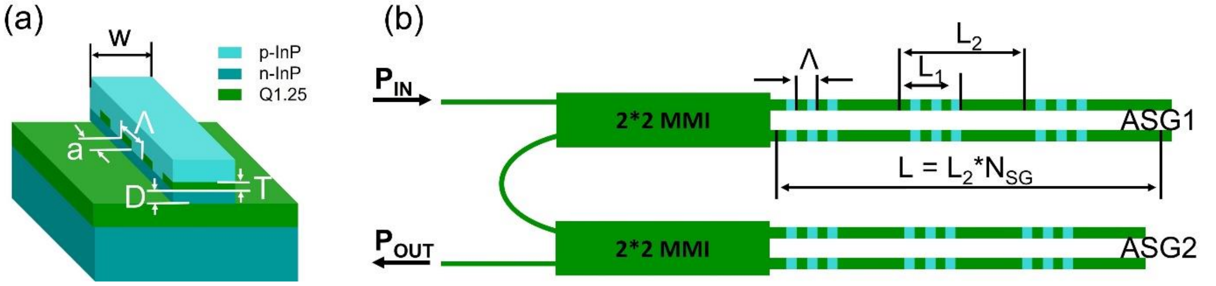

Fig. 1. (a): Schematic diagram of uniform DBRs in SMART Photonics platform. The layer stack has been simplified, without showing doping differences in p-InP and n-InP layers. (b): Schematic diagram of the top view of tunable filter.

Fig. 1(b) shows a schematic diagram of the tunable filter based on cascaded MMIs and ASGs. The device consists of two 2*2 MMIs with two sets of ASGs. The two ASGs in each set are nominally identical. When light is injected into the 3-dB MMI coupler, the light will be equally divided into two output ports with a π/2 phase difference. Then the light reflected from the ASG1 groups will be constructively imaged into the waveguide other than the input port. In this way, the device can guide the reflected and filtered light without the need of a circulator. By cascading such structures with slightly detuned ASGs, the Vernier effect can be achieved. It could enlarge the FSR for the filter to cover the C band. At the same time, by putting electrodes on different sets of ASGs, we could use current injection or reverse voltage bias to change the refractive index of the grating layer. Under this mechanism, the filter can be tuned with a wide range.

The sampled grating is composed of several gratings with straight waveguides in between. The period, the gratings length in each periodic section, the total number, and the total length of SGs are defined as L_2, L_1, N_{SG}, and L ($L = N_{SG}*L_2$). To easily characterize the sampled grating, we set dr_{SG} (= L_1/L_2) as the duty ratio of the sampled grating. The spacing between the peaks FSR_{SG} in the comb-like reflection spectrum can be calculated as follows,

$$FSR_{SG} = \frac{\lambda_{Bragg}^2}{2n_{eff}L_2} \tag{1}$$

It is known that the reflection spectrum from sampled grating always has a high side-lobe level around each peak, which leads to high crosstalk when it is used as a filter. In this case, the apodization method provides an efficient method to suppress the side-lobe extinction ratio, by modulating the refractive index difference in periodic structure, which has been widely used in Bragg grating structures[8]. In InP-based generic integration platform, since the κ constant and the duty ratio of the basic grating is fixed, we choose to modulate L_1 for the SG to achieve an effective apodization. Fig. 2(a) and (b) show n_{eq} and κ profiles of an ASG through modulating $L_1(i)$, where the L_1 in the center of the SG has a maximum L_{1m}. In this paper, Gaussian function is used to apodize the SG as follow,

$$dr_{SG}(i) = dr_{SGm} * \exp\left(-\left(\frac{2.24\left(i-\frac{N_{SG}}{2}\right)}{N_{SG}}\right)^2\right) \qquad i = [1, N_{SG}] \tag{2}$$

where dr_{SGm} is the maximum duty ratio in the center of the SG, which equals L_{1m}/L_2. The i is the section number for the SG. Fig. 2(c) shows the dr_{SG} curves under Uniform (non-apodization) and Gaussian apodization function modulation with N_{SG} = 20 and dr_{SGm} = 0.2. The Uniform function has a constant dr_{SG} of 0.2, while the Gaussian function modulated dr_{SG} curve changes symmetrically, from around 0.07 at edges to 0.2 at the center of the SG.

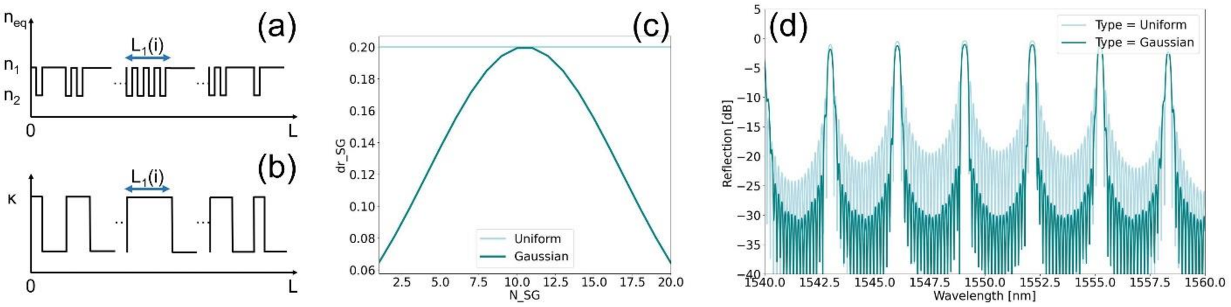

Fig. 2. Schematic diagrams of (a): refractive index profile and (b): the coupling coefficient profile of an apodized sampled grating by modulating the grating length L1. (c): The dr_{SG} curves of sampled grating under Uniform and Gaussian function apodization (N_{SG} = 20, dr_{SGm} = 0.2). (d) The reflection spectrums of Uniform SG and Gaussian-type ASG with same fundamental parameters (N_{SG} = 20, L_2 = 100 μm, dr_{SGm} = 0.2).

Fig. 2(d) shows the calculated reflection spectrum through Transfer Matrix Method under Uniform and Gaussian type apodization, with $N_{SG} = 20$, $L_2 = 100$ µm, $dr_{SG} = 0.2$, and $FSR_{SG} = 3.68$ nm. The SER and IL of the reflected spectrum for Uniform-type sampled grating are around 6.90 dB and 0.42 dB, respectively, but the SER for Gaussian-type ASG has been significantly increased to around 19.46 dB, which clearly shows that the Gaussian apodization method is more promising. However, the ~1.03 dB IL is a bit higher for Gaussian-type than the Uniform-type, which can be compensated by increasing the number of N_{SG}. Due to the low coupling efficiency of the grating, the 3 dB bandwidth is quite small, which is less than 0.3 nm. The distorted modes far away from the central wavelength are mainly because of the phase mismatch caused by the effective index changing along the sampled grating.

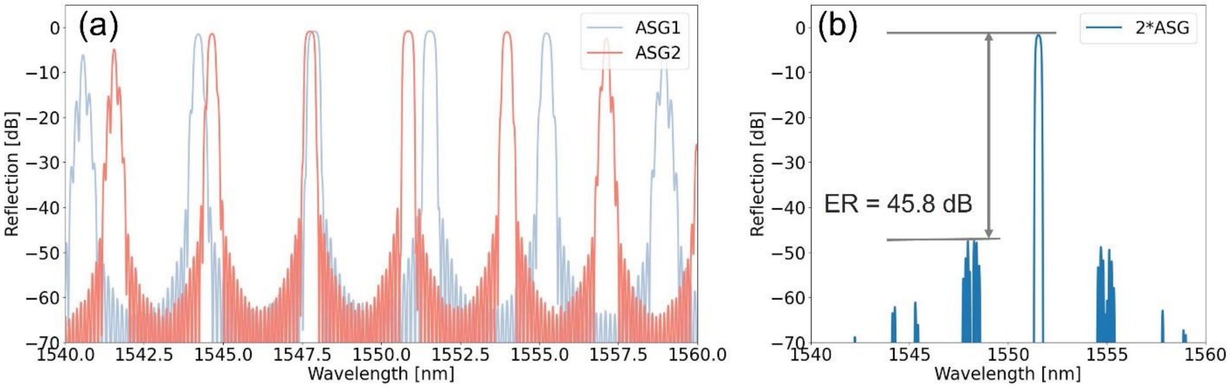

Fig. 3. (a): The reflection spectrums of two Gaussian-type apodized sampled gratings, separately. (b): The reflection spectrum of two cascaded Gaussian-type apodized sampled gratings.

When choosing the parameters for two cascaded ASGs for Vernier effect, the FSR of filter should be considered, which is defined as,

$$FSR = \frac{FSR_{SG1}*FSR_{SG2}}{FSR_{SG2}-FSR_{SG1}} \tag{3}$$

where FSR_{SG1} and FSR_{SG2} are the peak spacing in the reflection spectrum of ASG1 and ASG2 ($FSR_{SG1} < FSR_{SG2}$), respectively. When choosing the L_1 of ASG1 and ASG2 as 100 µm and 118 µm respectively, we can achieve an FSR larger than 20 nm. The final optimized parameters for ASG1 and ASG2 are $N_{SG1} = N_{SG2} = 25$, $dr_{SGm1} = 0.325$, $dr_{SGm2} = 0.3$. Fig. 3(a) shows the reflection spectrum of two Gaussian-type ASGs, in which the SER are both higher than 40 dB, and the IL less than 1 dB. The reflection spectrum of the cascaded two Gaussian-type ASGs, shown in Fig. 3(b), shows a narrow BW = 0.3 nm with high ER > 45 dB, SER > 80 dB, and low IL < 1.75 dB. When considering the loss of MMI ($IL_{MMI} = 0.75$ dB), we predict the IL for the filter to be less than 5 dB.

DISCUSSION

In this paper, we propose a narrow bandwidth tunable optical filter using cascaded ASGs. Through Gaussian-type apodization on the duty ratio of the SG periodically, the side-lobe extinction ratio can be highly reduced. The filter can achieve a high extinction ratio > 45 dB, low insertion loss < 5 dB, narrow 3 dB bandwidth < 0.3 nm, and wide FSR > 20 nm, which is a promising device on optical integration circuits for THz heterodyne system.

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